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(54) **Structural systems for panels, boards, shelves, and laminates**

(57) Structures are developed from substantially planar sheets 10 of relatively inflexible material formed with two interdigitating patterns 11 and 12 of preferred bending. One pattern 11 is designed to facilitate bending out of the plane of the sheet on one side of that plane and the other pattern 12 is designed to facilitate bending out of the plane on the other side thereof. Each pattern 11 or 12 comprises a non-linear backbone 13 or 14 of straight lines 17 or 18, joined in end to end relationship, and having a plurality of straight ribs 15 or 16 extending transversely of the backbone. Each rib 15 or 16 has one end juxtaposed with the junction of two lines 17 or 18 in the backbone of its pattern 11 or 12 and the other end in juxtaposition with the junction of two lines 18 or 17, respectively, in the backbone of the other pattern 12 or 11, the patterns being such that no line crosses a line of the same or of the other pattern. The invention is characterised in that the sum of the angle between a rib 15 or 16 and one of the juxtaposed lines 17 or 18 of the backbone 13 or 14 or its pattern 11 or 12 and the angle between the other of those juxtaposed lines 17 or 18 and the rib 16 or 15, respectively, of the other pattern juxtaposed therewith is not equal to 180°.

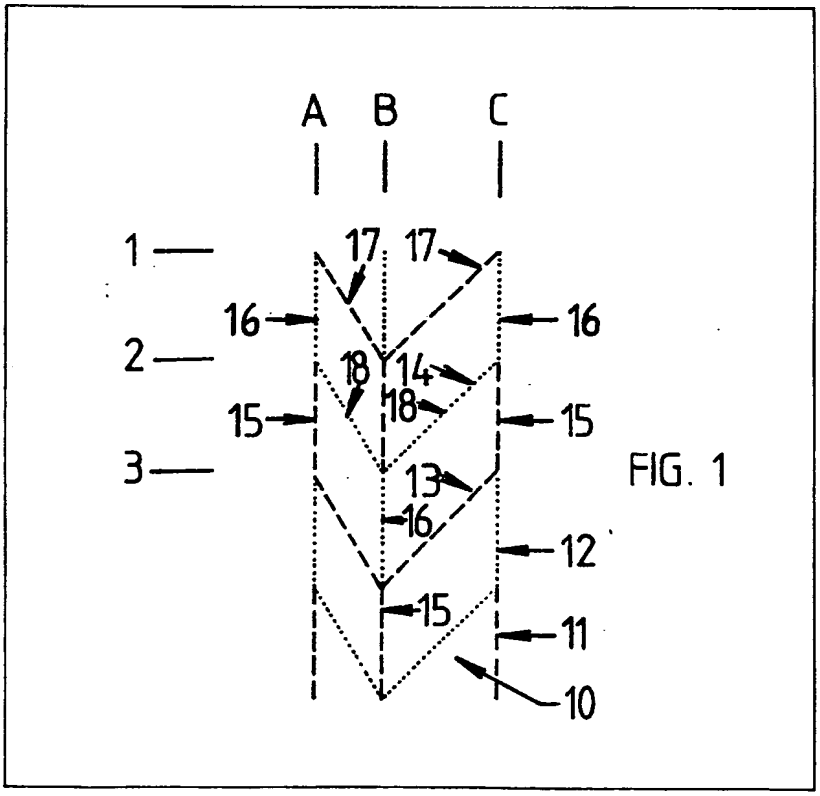

FIG. 1

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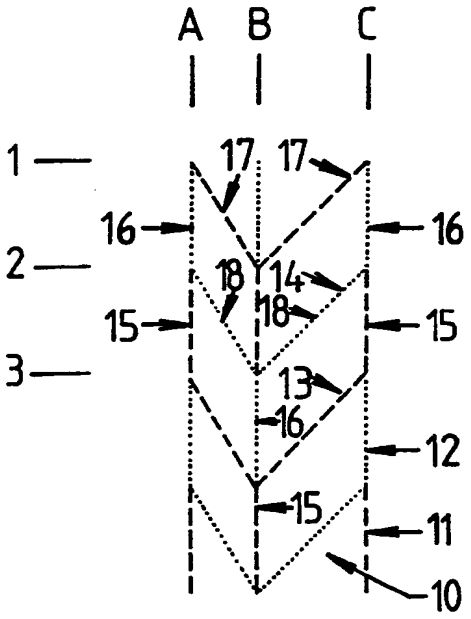


FIG. 1

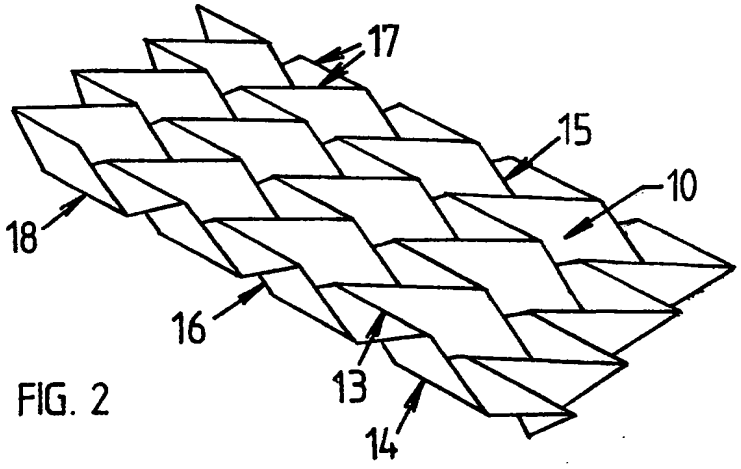


FIG. 2

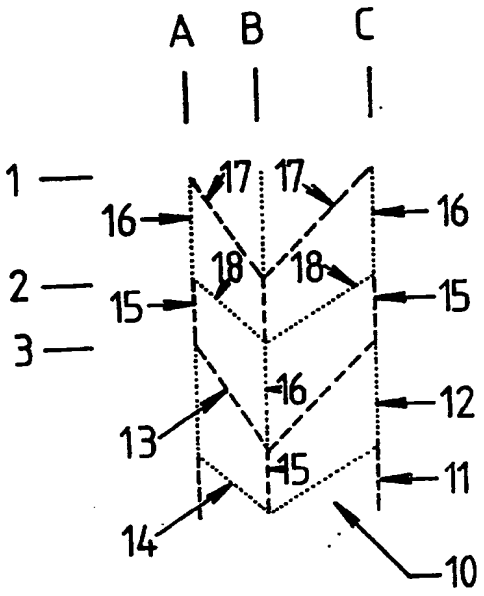


FIG. 3

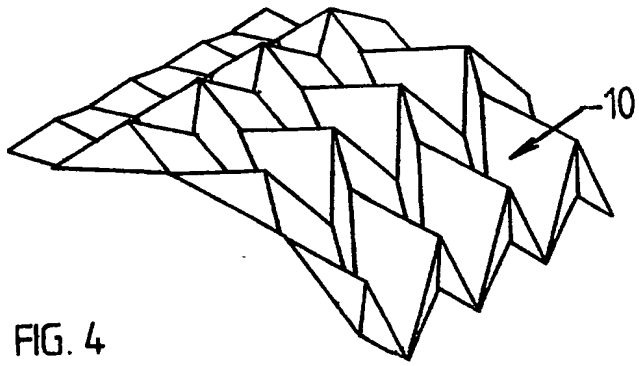
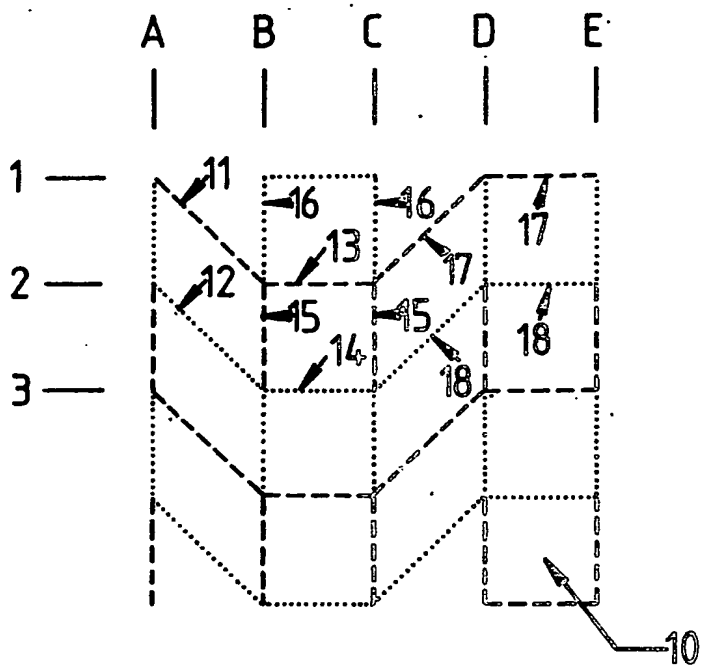


FIG. 4


A
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C
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10

FIG. 5

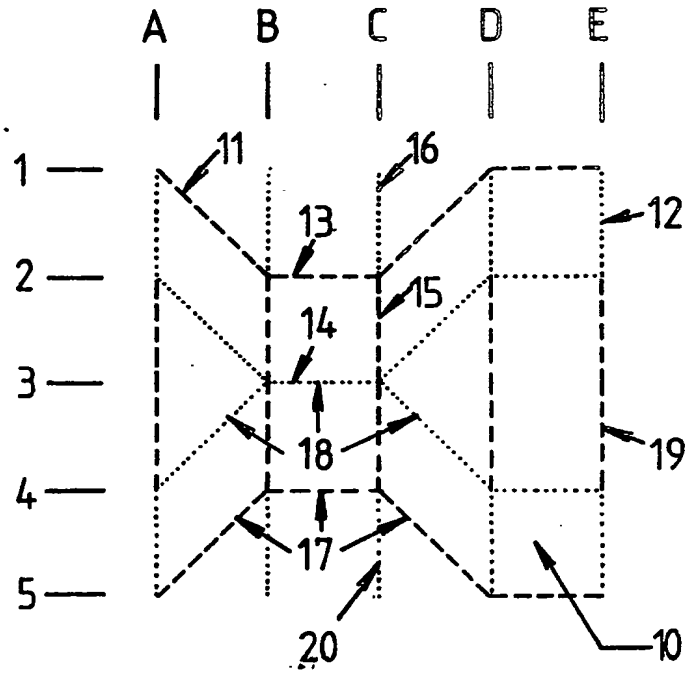
A
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FIG. 15

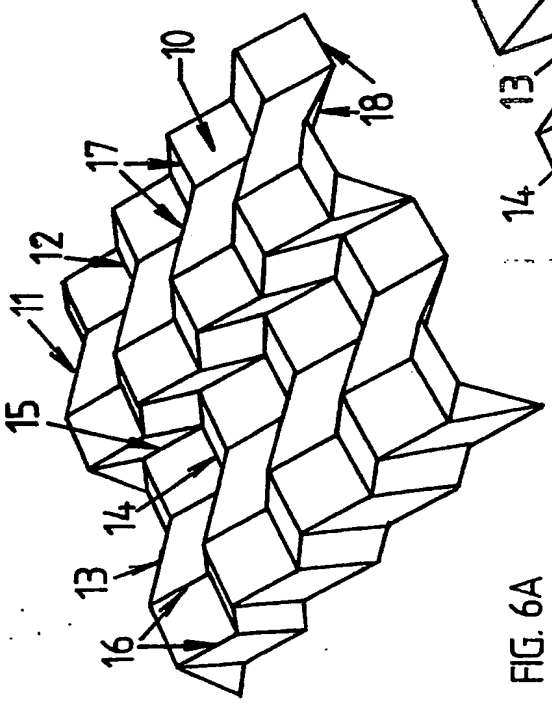

FIG. 6A

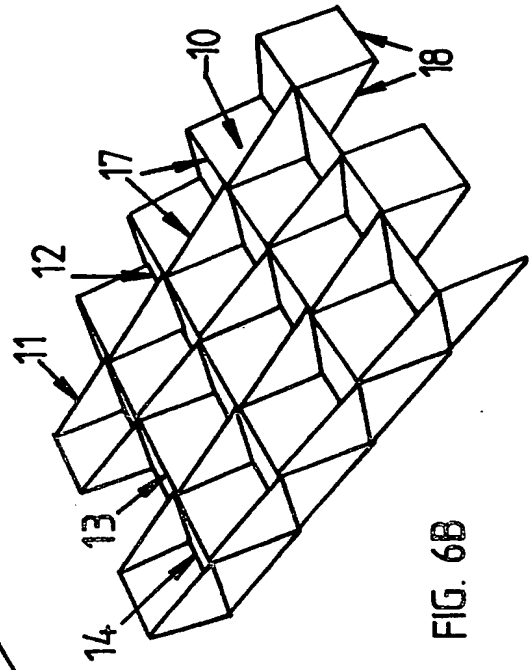

FIG. 6B

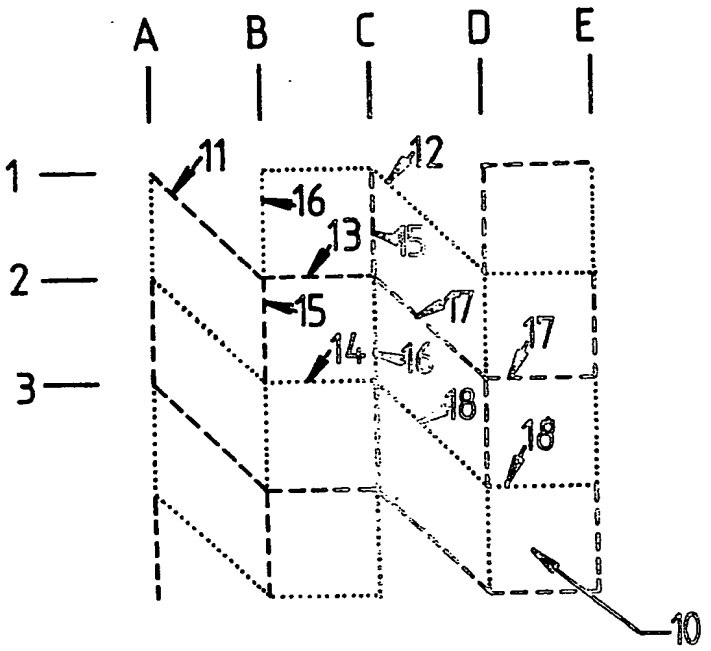

FIG. 7

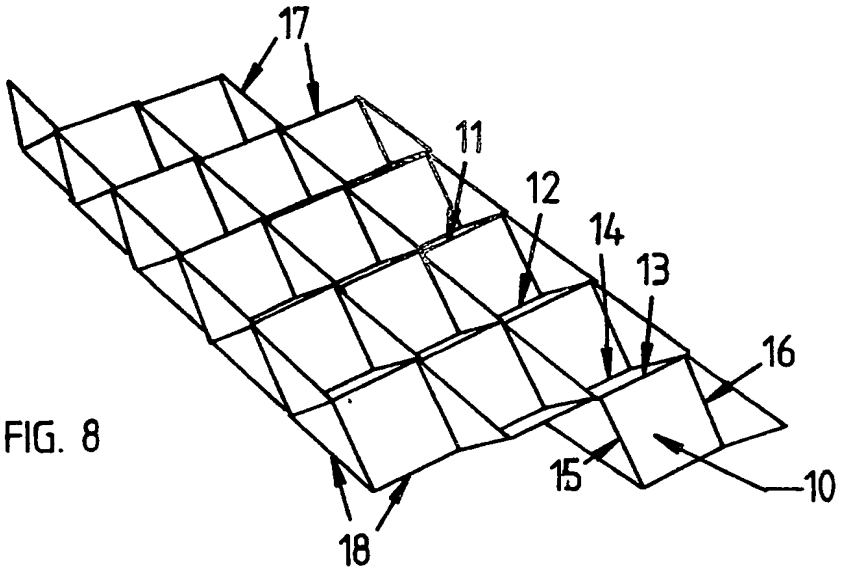

FIG. 8

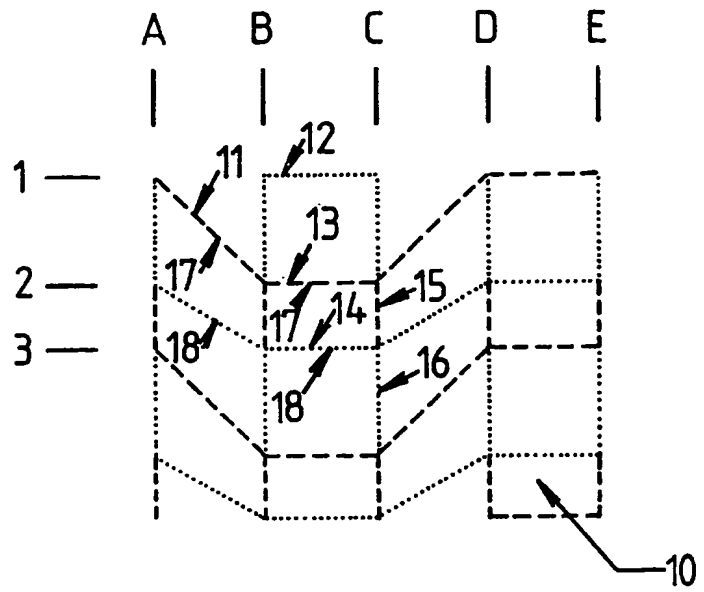

FIG. 9

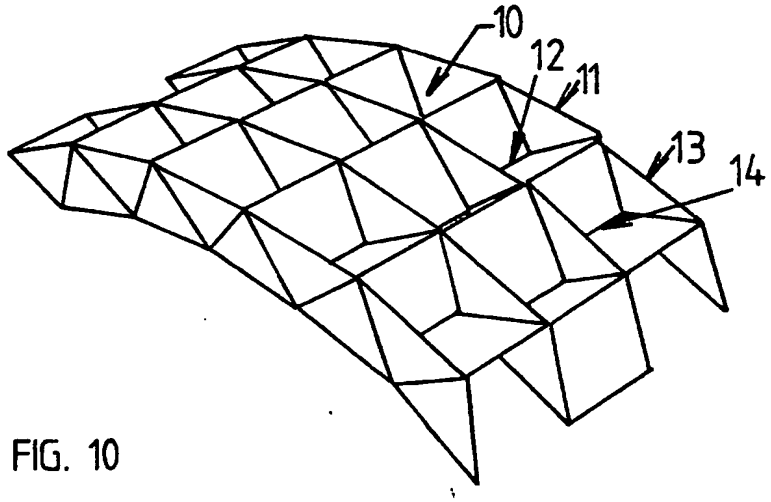

FIG. 10

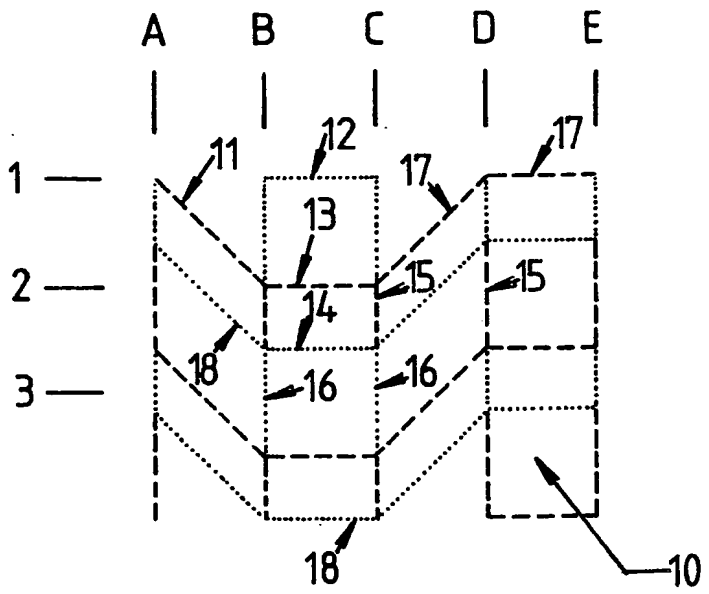

FIG. 13

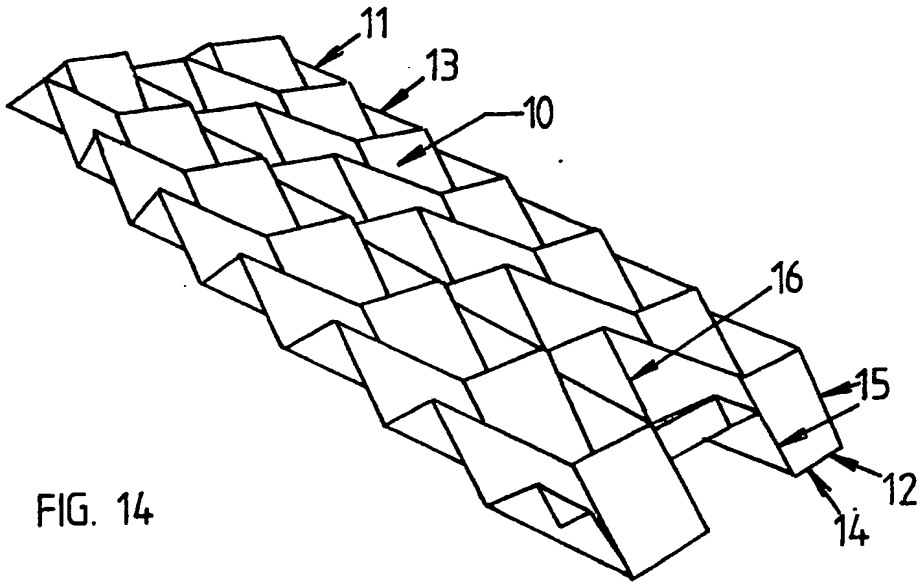

FIG. 14

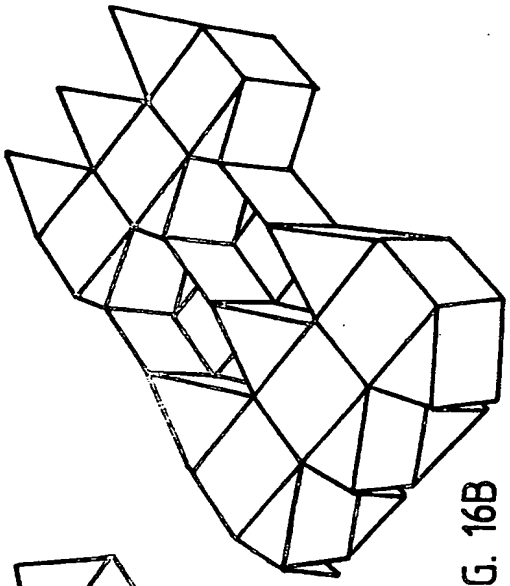

FIG. 16B

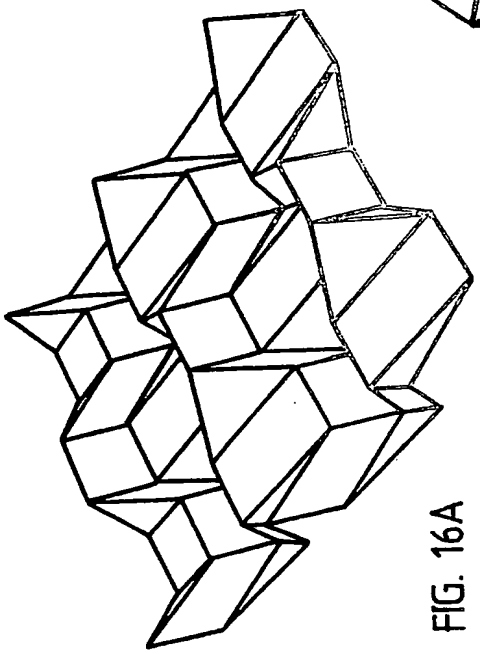

FIG. 16A

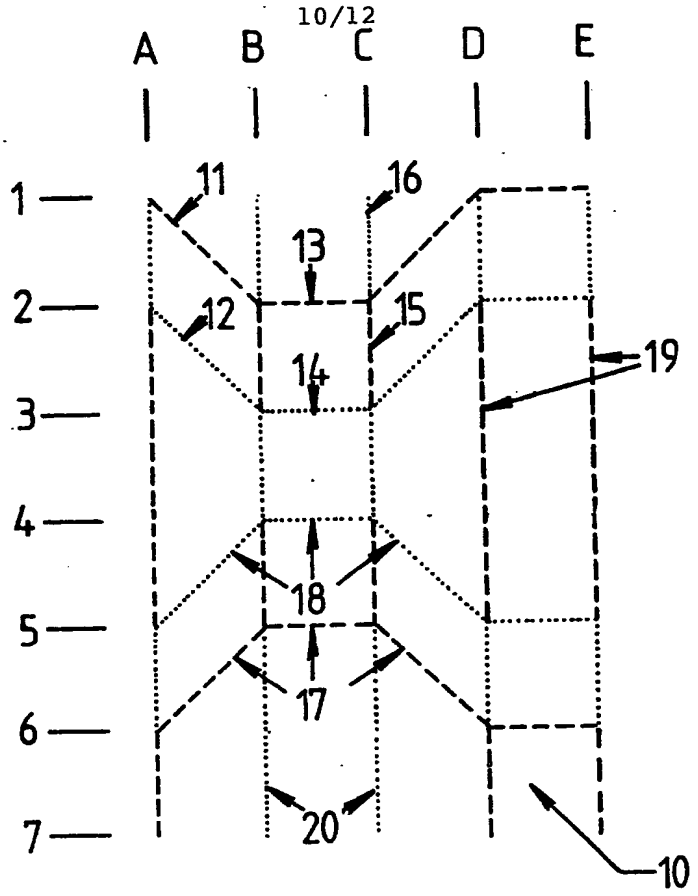

FIG. 17

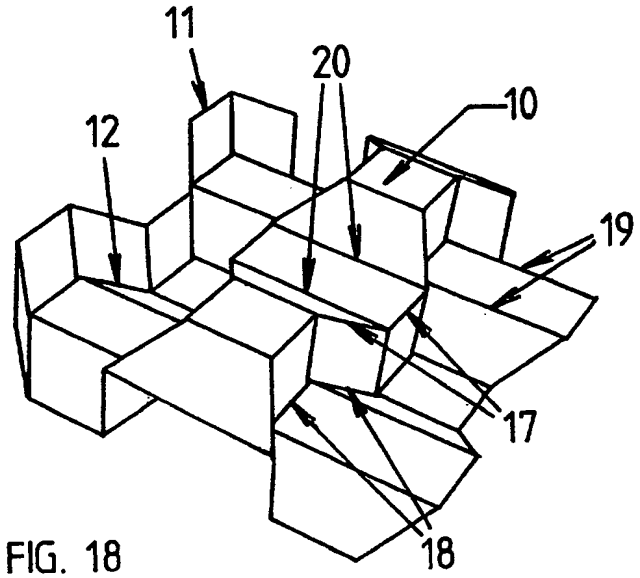

FIG. 18

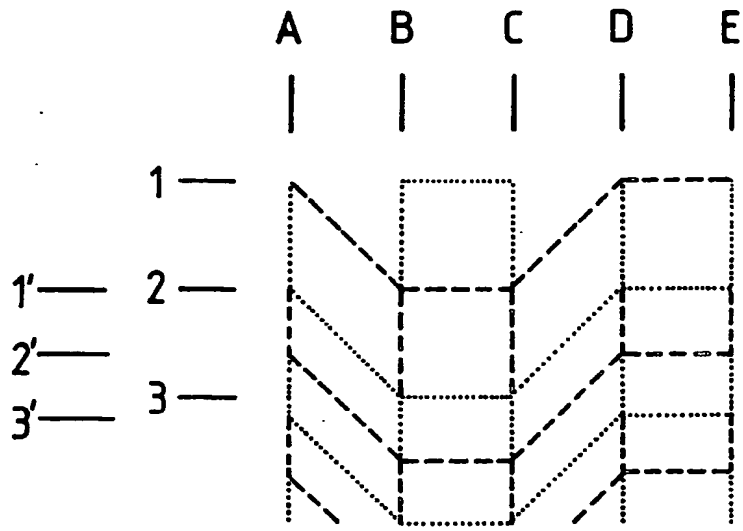

FIG. 19

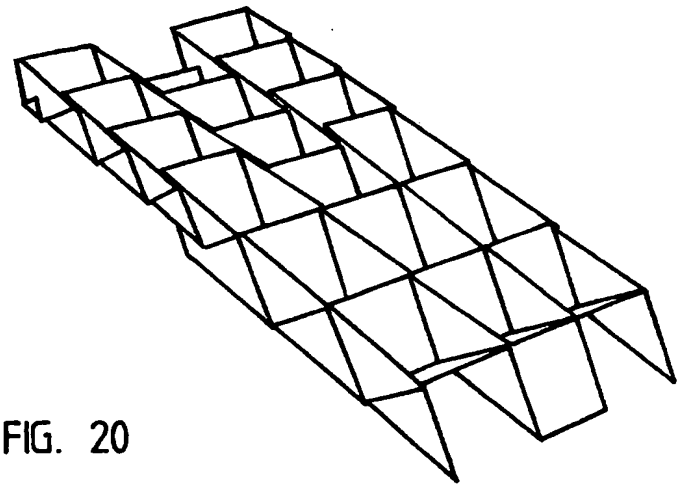

FIG. 20

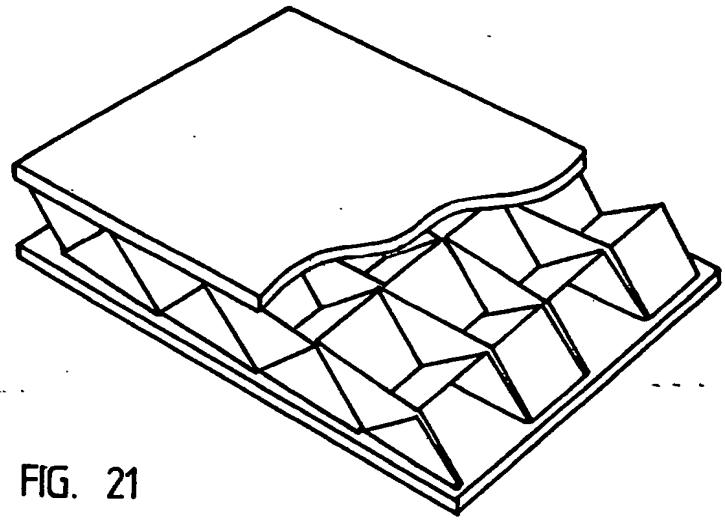

FIG. 21

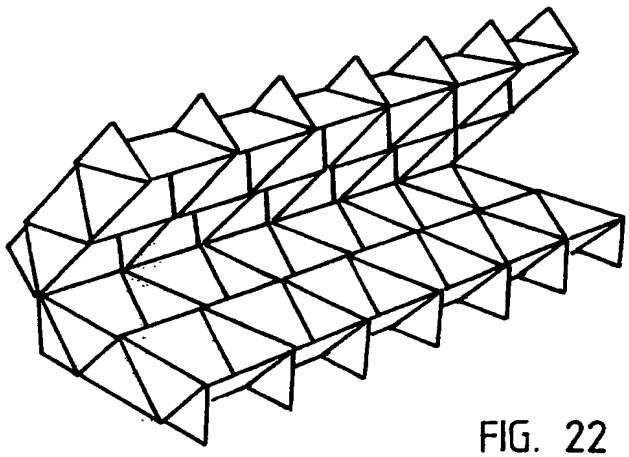

FIG. 22

SPECIFICATION

Structural systems for panels, boards, shelves and laminates

The present invention relates to a substantially planar sheet material provided with two patterns of preferred bending such that the sheet may, by the application of compressive forces in the plane of the sheet develop into a three dimensional array of ridges and valleys. The invention further relates to structures consisting of or including a sheet so developed.

It is known to form planar sheets with two patterns of preferred bending such that upon the application of compressive forces in the plane of the sheet develop into a three dimensional array of ridges and valleys. Such sheets are disclosed in French patent specification 1,349,879, in German patent specification 2,530,661 and in German patent specification 1,434,112. In all of the sheets described in these specifications the patterns of each comprise a non-linear backbone of straight lines, joined together in end to end relationship, and a plurality of straight ribs extending transversely of the backbone. Each rib in each pattern terminates at one end in juxtaposition with the junction of two lines in the backbone of that pattern and at the other end in juxtaposition with the junction of two lines in the backbone of the other pattern. In all of the prior art specifications the rib bisects the angle between the two juxtaposed lines of the backbone of its pattern i.e. the angles between the rib and each of the juxtaposed lines of its backbone are equal. A corollary of this is that the sum of the angle between a rib and one of the juxtaposed lines of the backbone of its pattern and the angle between the other of those juxtaposed lines and the rib of the other pattern juxtaposed therewith is always equal to 180°. In this arrangement the application of compressive forces in the plane of the sheet will develop the sheet into a three dimensional array of ridges and valleys. Further compression will cause the sheet to collapse into a concertina-like array of vertical sheet segments abutting in a face to face relationship i.e. there is a continuous transition between the sheet in a horizontal, planar form and the sheet in a collapsed, concertina-like, form with the sheet segments lying in face to face vertical array.

It will also be apparent that in such a sheet the thickness of the developed sheet will be dependent upon the degree of which the sheet has been compressed by the application of forces in the plane of the sheet. If the sheet, when developed, is to have a uniform thickness then the patterns on the sheet must be repeated uniformly. This makes it impossible to introduce into the sheet localised pattern changes which can result in localised increases in strength in the developed sheet or in structures consisting of or including a sheet so developed.

The present invention is directed to a novel pattern for use in such sheets in which there is a disjunction in the collapsing of the sheet by the application of compressive forces in the plane of the sheet such that the sheet "locks up" in a condition in which some of the sheet segments lie in face to face abutment and some lie transversely to such face to face segments. The novel patterns according to preferred embodiments of this invention allow the creation of localised areas of increased strength in sheets of uniform developed thickness.

The present invention consists in a substantially planar sheet of relatively inflexible material formed with two interdigitating patterns of preferred bending, one pattern being designed to facilitate bending out of the plane of the sheet on one side of that plane and the other pattern being designed to facilitate bending out of the plane on the other side thereof, each pattern comprising a non-linear backbone of straight lines, joined together in end to end relationship, and having a plurality of ribs, constituted by straight lines, extending transversely of the backbone, each rib terminating at one end in juxtaposition with the junction of two lines in the backbone of its pattern and at the other end in juxtaposition with the junction of two lines in the backbone of the other pattern, the patterns being such that no line crosses a line of the same or of the other pattern, the present invention being characterised in that the sum of the angle between a rib and one of the juxtaposed lines of the backbone of its pattern and the angle between the other of those juxtaposed lines and the rib of the other pattern is not equal to 180°; such that the sheet is capable, by the application of compressive forces in the plane of the sheet to develop into an array of ridges and valleys which can lock-up (as herein defined).

The present invention further consists in a structure consisting of or including a sheet according to the present invention developed into a three dimensional array of ridges and valleys.

As used in the present specification sheets of the type to which this invention relates are said to lock-up when some segments of the sheet defined by the pattern will lie in face to face abutment while other segments thereof will lie transversely to the plane of such face to face abutment.

In preferred embodiments of the present invention each of the patterns will be made up of a plurality of identical pattern units placed in a continuous array of side by side and end to end pattern units. In other embodiments however there could be a continuous transition or change in the pattern throughout the sheet. This transition or change in the pattern could comprise changes in the relative angular relationship between lines in the backbone or between such lines and the ribs; it could comprise changes in the lengths of the lines in the backbone or the ribs; or it could comprise a combination of both of these factors.

The two patterns of preferred bending are preferably applied as one pattern on each side of the sheet such that juxtaposed ends of lines in the two patterns will be separated by the thickness of the sheet. The nature of the patterns will vary depending upon the material of the sheet. If the sheet were of a relatively rigid thermoplastic material the patterns may be applied by heat to cause lines of weakness, and thus

preferred bending, on each side of the sheet. In the case of a cardboard sheet the patterns of preferred bending may be cut into each side of the cardboard sheet. If the sheet were of metal then the pattern could be embossed into the metal with a die. The above examples are illustrative only as other materials could be used to form the sheet and other methods could be used to form in the sheet the patterns of preferred bending.

It is also within the ambit of the invention to form the sheet from a plurality of sheet segments hingedly connected together by flexible elements. The hinged connections being disposed along the pattern lines. Each pattern includes a rib terminating in juxtaposition with every junction between two lines of the backbone of that pattern. Similarly each pattern includes a rib of the other pattern terminating in juxtaposition with every junction between two lines of the backbone of that pattern.

In describing the preferred patterns falling within the ambit of this invention it is useful to describe only one unit of each of the patterns for any one sheet. This may conveniently be done with reference to a notional rectilinear grid defining the locus of the junction between the lines of the backbones of the two patterns and of the junctions between the ribs and the backbones. In order to facilitate this description the lines of the notional grid extending in a vertical direction are given alpha designations e.g. A, B, C. etc., while the horizontal lines are given numeric designations e.g. 1, 2, 3 etc. Thus a pattern which had two backbone lines as the basic unit could be described by a grid having vertical lines A, B and C and horizontal lines 1, 2 and 3. A pattern which have four backbone lines in the basic unit could be described by a grid having vertical lines A, B, C, D and E and horizontal lines 1, 2 and 3. It will be appreciated that the junctions of the lines in the patterns do not have to fall on a rectilinear grid however for the purposes of description it is useful to use examples which do.

In one preferred embodiment of the invention the pattern unit comprises two backbone lines and has ribs no longer than one grid unit and may thus be defined by a grid having vertical lines A, B and C and horizontal lines 1, 2 and 3. In this preferred embodiment the distance between lines 1 and 2 is equal to the distance between lines 2 and 3 but the distance between A and B is greater than between B and C. The pattern on one side of the sheet comprises a backbone extending from A2 to B3 to C2 with ribs extending from A2 to A1, B2 to B1, and C2 to C1. The pattern on the other side of the sheet comprises a backbone extending from A1 to B2 to C1 with ribs extending from A2 to A3, B2 to B3, and C2 to C3. This represents probably the simplest form of the invention and results in a three dimensional structure of uniform thickness defined between two notional planes (hereinafter called a flat structure) which will lock up.

A variation of the foregoing may be developed by providing a notional grid in which the distance between lines 1 and 2 does not equal the distance between lines 2 and 3. This embodiment of the invention results in a three dimensional structure which is of uniform thickness and locks up but which lies between two notional curved surfaces i.e. the developed structure is curved rather than flat as in the previous case.

A further preferred group of embodiments are those defined by a notional 5 by 3 grid in which the distances between each pair of adjacent vertical and each pair of adjacent horizontal lines is equal. In this embodiment the pattern on one side of the sheet comprises a backbone extending from A1 to B2 to C2 to D1 to E1 with ribs extending from A2 to A3, B2 to B3, C2 to C3, D2 to D3 and E2 to E3. The pattern on the other side of the sheet comprises a backbone extending from A2 to B3 to C3 to D2 to E2 with ribs extending from A1 to A2, B1 to B2, C1 to C2, D1 to D2 and E1 to E2. This embodiment of the invention develops into a flat structure which locks up. This structure is interesting because the segments of the sheet which do not lie in face to face abutment when the sheet is locked up lie at right angles to the planes of such face to face abutment.

Another embodiment of the invention which develops into a very similar structure as the foregoing may be described with reference to the notional grid of the preceeding paragraph. In this embodiment the pattern on one side of the sheet comprises a backbone extending from A1 to B2 to C2 to D3 to E3 with ribs extending from A2 to A3, B2 to B3, C1 to C2, D1 to D2 and E2 to E3. The pattern on the other side of the sheet comprises a backbone extending from A2 to B3 to C3 and from C1 to D2 to E2 with ribs extending from A1 to A2, B1 to B2, C2 to C3, D2 to D3 and E1 to E2. It will be noted that in this case there appears to be a disjunction in the backbone on the other side of the sheet. In practice, of course, the backbone is continuous as it progresses from pattern unit to pattern unit.

The foregoing 5 by 3 notional grid may be used to produce other embodiments of this invention. If the distance 1 to 2 and 2 to 3 are made unequal then a curved lock-up structure will be produced. In another embodiment the distances between A and B, and B and C and C and D and D and E may be non-uniform in which case the spacings between the segments in face to face abutment when the three dimensional structure locks up will vary. This feature may be used to produce structures having different strengths in different parts of the structure.

Embodiments of the invention may also be produced in which separate notional grids are used for the patterns on each side of the sheet. If these notional grids are of the same dimensions but horizontally and/or vertically displaced from one another the resultant locked up structure will have a stepped form rather than a flat or curved form.

It is also possible to produce patterns based on larger notional grids. Some of these may include patterns which show an axis of symmetry, the pattern or each side of the axis being a pattern unit in its own right which if repeated would give rise to a sheet according to this invention. It is also possible for the notional grid to change abruptly or gradually through a sheet to give rise to consequent changes in the structure developed from the sheet.

The sheets according to this invention may be formed up into a three dimensional structure, either to the lock up stage or to some intermediate position,

and laminated between planar, curved or stepped sheets to form structural laminates. These structural laminates could, for instance, be used as building panels or as impact resistant packing material. The structures formed merely by forming up the sheet into its three dimensional form can, for instance, be used as sound deadening material or as a packaging material. Such structures could also be used as formwork to produce aesthetic surface effects on cast concrete.

Hereinafter given by way of example only are preferred embodiments of the present invention described with reference to the accompanying drawings in which:

Fig. 1 is a representation of the two patterns of preferred bending on one embodiment of the sheet according to this invention;

Fig. 2 is a perspective view of a locked up three dimensional structure developed from a sheet having the pattern of preferred bending of Fig. 1;

Fig. 3 is a representation of the two patterns of preferred bending on a further embodiment of the sheet according to this embodiment;

Fig. 4 is a perspective view of a locked up three dimensional structure developed from a sheet having the patterns of preferred bending of Fig. 3;

Fig. 5 is a representation of the two patterns of preferred bending on a further embodiment of a sheet according to this invention;

Fig. 6A is a perspective view of a three dimensional structure partly developed from a sheet having the pattern of prefered bending of Fig. 5;

Fig. 6B is a perspective view of the structure of Fig. 6A developed to a locked up position;

Fig. 7 is a representation of the two patterns of preferred bending on a further embodiment of the sheet according to this invention;

Fig. 8 is a perspective view of a locked up three dimensional structure developed from a sheet having the patterns of preferred bending of Fig. 7;

Fig. 9 is a representation of the two patterns of preferred bending on a further embodiment of a sheet according to this invention;

Fig. 10 is a perspective view of a locked up three dimensional structure developed from a sheet having the patterns of preferred bending of Fig. 9;

Fig. 11 is a representation of the two patterns of preferred bending on a further embodiment of a sheet according to this invention;

Fig. 12 is a perspective view of a locked up three dimensional structure developed from a sheet having the patterns of preferred bending of Fig. 11;

Fig. 13 is a representation of the two patterns of preferred bending on a further embodiment of a sheet according to this invention;

Fig. 14 is a perspective view of locked-up three dimensional structure developed from a sheet having the patterns of preferred bending of Fig. 13;

Fig. 15 is a representation of the two patterns of preferred bending on a further embodiment of a sheet according to this invention;

Fig. 16A is a perspective view of a three dimensional structure partly developed from a sheet having the patterns of preferred bending of Fig. 15;

Fig. 16B is a perspective view of the structure of Fig. 16A developed to a locked up position;

Fig. 17 is a representation of the two patterns of preferred bending on a further embodiment of a sheet according to this invention;

Fig. 18 is a perspective view of a three dimensional structure partly developed from a sheet having the patterns of preferred bending of Fig. 17;

Fig. 19 is a representation of the two patterns of preferred bending on a further embodiment of a sheet according to this invention;

Fig. 20 is a perspective view of a locked-up three dimensional structure developed from a sheet having the patterns of preferred bending of Fig. 10;

Fig. 21 is a perspective view of a laminate incorporating a three dimensional structure formed from a sheet according to this invention; and

Fig. 22 is a container comprising a three dimensional structure formed from a sheet according to this invention.

In the following description of the various embodiments of the invention illustrated the same numbers will be used for similar integers.

With reference to Figs. 1 and 2 the cardboard sheet 10 is formed with two patterns of preferred bending. The first pattern 11, which is shown in dashed lines, defines an array of lines of preferred bending which will rise above the plane of the sheet 10 as depicted in Fig. 1 when the sheet is developed into a three dimensional Fig. 2. The second pattern 12, which is shown in dotted lines, defines an array of lines of preferred bending which will fall below the plane of the sheet 10 when so developed.

The patterns 11 and 12 are each formed by cutting into the cardboard through approximately half its thickness. The pattern 11 is formed on the upper surface of the sheet 10 as seen in Fig. 1, and the pattern 12 is formed on the lower surface thereof.

Each of the patterns 11 and 12 comprise a recurring array of abutting pattern units which are in register with one another. Each pattern comprises a backbone, 13 in pattern 11 and 14 in pattern 12, and a plurality of straight ribs, 15 in the pattern 11 and 16 in pattern 12. Each of the backbones is non-linear and made up of a plurality of straight lines, 17 in pattern 11 and 18 in pattern 12, connected end to end. Each rib 15, 16 is connected at one end to a junction between two lines 17, 18 of the backbone 13, 14 of its own pattern and is connected at its other end to a junction between two lines 17, 18 of the backbone 13, 14 of the other pattern.

The units of patterns 11 and 12 may each be described with reference to a single 3 by grid 3 grid comprising parallel vertical lines A, B and C and parallel horizontal lines 1, 2 and 3. In the case of Fig. 1 the distance between 1 and 2 equals the distance between 2 and 3 but the distance between A and B is greater than the idstance between B and C. The spacing between lines A, B and C means that the angles between each rib 15, 16 and the adjacent lines 17, 18, is not equal and thus the sum of the diagonally opposed pairs of angles α and τ, and β and δ, are not equal to 180°. In the case of pattern 11 the angle between line 17 extending from A1 to B2 and the rib 15 extending from B2 to B3 is smaller than the angle between that rib 15 and the line 17 extending from B2

to C1.

As is seen in Fig. 2 compression of the sheet 10 of Fig. 1 in the plane of the sheet developes the sheet into a three dimensional structure comprising an array of ridges and valleys. Because of the angular relationship between the ribs 15, 16 and the lines 17, 18 of the backbones 13, 14 the segments of the sheet between B and C lines of the grid will come into face to face abutment while the segments between the A and B lines are still extending transversely to the plane of that abutment i.e. the structure "locks-up" before it is fully collapsed. In the embodiment of the invention shown in Fig. 2 the three dimensional structure is flat, i.e. the crests of the ridges and valleys lie in two parallel planes.

The embodiment shown in Figs. 3 and 4 is similar to that shown in Figs. 1 and 2 except that the distance between grid lines 1 and 2 is smaller than that between lines 2 and 3. A three dimensional structure similar to that of Fig. 2 can be developed from the sheet of Fig. 3 except that the structure is curved.

The embodiment shown in Fig. 5, 6A and 6B is similar to that shown in Figs. 1 and 2 except that the grid is square but based on a 5 by 3 unit rather than a 3 by 3 unit. This allows the angles between each rib 15, 16 and the adjacent lines 17, 18 to be unequal without the spacings between lines A, B, C, D and E being unequal. As is seen in Figs. 6A and 6B the sheet 10 of Fig. 5 develops a flat three dimensional structure and locks-up.

The embodiment shown in Figs. 7 and 8 is very similar to that shown in Figs. 5, 6A and 6B except that the backbones of the embodiment of Fig. 5 have an essentially wave-like form whereas those of Fig. 7 have an essentially stepped form.

The embodiment shown in Figs. 9 and 10 is similar to that of Figs. 5, 6A and 6B except that the spacing between lines 1 and 2 is greater than the spacing between lines 2 and 3. As is seen in Fig. 10 the sheet 10 of Fig. 9 develops as a curved three dimensional structure which locks-up.

The embodiment shown in Figs. 11 and 12 is similar to that of Figs. 5, 6A and 6B except that the spacings between lines A, B, C, D and E are not equal. As is seen in Fig. 12 the sheet 10 of Fig. 11 develops as a flat three dimensional structure which locks up. In this case the segments between the A and B lines lock-up before any of the other segments come into face to face contact, thus all the segments lie transversely to the A, B segments when the structure is locked-up.

The embodiment shown in Figs. 13 and 14 is similar to that of Figs. 5, 6A and 6B except that the patterns 11 and 12 are based on grids which are displaced from one another in a vertical direction. As is seen in Fig. 14 the sheet 10 of Fig. 13 develops as a stepped three dimensional structure which locks-up.

The embodiment shown in Figs. 15, 16A and 16B is similar to that of Figs. 5, 6A and 6B except that the patterns 11 and 12 each comprises the 5 by 3 unit of Fig. 5 together with the mirror image of that unit. The pattern unit of the embodiment of Fig. 15 is thus based on a 5 by 5 grid rather than a 5 by 3 grid. It will be noted that in this embodiment the patterns 11, 12 includes not only the backbones 13, 14 and ribs 15, 16 but also successive islands 19, 20 isolated from the remainder of that pattern 11, 12 by the other of the patterns 12, 11. As is seen in Figs. 16A and 16B the sheet 10 of Fig. 15 develops into a corrugated locked-up structure.

The embodiments shown in Fig. 17 and 18 is very similar to that of Figs. 15, 16A and 16B except that the patterns 11 and 12 are stretched such that they are based on a 5 by 7 grid rather than a 5 by 5 grid. Fig. 18 shows a three dimensional structure formed from the sheet 10 of Fig. 17 which has been only partly developed and stopped prior to reaching the locked-up stage.

The embodiment shown in Figs. 19 and 20 is the same as the embodiment shown in Figs. 5, 6A and 6B except that there is a horizontal dimensional transition from the grid designated 1, 2 and 3 to the grid designated 1', 2' and 3'. This dimensional transition is reflected in the change in thickness of the developed, locked-up, structure shown in Fig. 20.

Fig. 21 shows a laminated structure comprising the structure of Fig. 6B sandwiched between two planar sheets. Fig. 22 shows a container formed from the developed structure of Fig. 6B.

CLAIMS

1. A substantially planar sheet of relatively inflexible material formed with two interdigitating patterns of preferred bending, one pattern being designed to facilitate bending out of the plane of the sheet on one side of that plane and the other pattern being designed to facilitate bending out of the plane on the other side thereof, each pattern comprising a non-linear backbone of straight lines, joined together in end to end relationship, and having a plurality of ribs, constituted by straight lines, extending transversely of the backbone, each rib terminating at one end in juxtaposition with the junction of two lines in the backbone of its pattern and at the other end in juxtaposition with the junction of two lines in the backbone of the other pattern, the patterns being such that no line crosses a line of the same or of the other pattern, the present invention being characterised in that the sum of the angle between a rib and one of the juxtaposed lines of the backbone of its pattern and the angle between the other of those juxtaposed lines and the rib of the other pattern is not equal to 180°; such that the sheet is capable, by the application of compressive forces in the plane of the sheet to develop into an array of ridges and valleys which can lock-up (as herein defined).

2. A substantially planar sheet of relatively inflexible material as claimed in claim 1 in which each of the pattern is made up of a plurality of pattern units placed in side by side and end to end register.

3. A substantially planar sheet of relatively inflexible material as claimed in claim 1 in which one pattern of preferred bending is applied to one side of the sheet and the outer pattern of applied bending is applied to the other side of the sheet.

4. A substantially planar sheet of relatively inflexible material as claimed in claim 1 in which the angle between a rib and one of the juxtaposed lines of the backbone of its pattern is 90°.

5. A substantially planar sheet of relatively inflexible material as claimed in claim 2 in which each pattern unit is based on a national grid comprising

three longitudinal lines and five vertical lines.

6. A substantially planar sheet of relatively inflexible material as claimed in claim 5 in which the grid upon which each pattern unit is based has the longitudinal lines uniformly spaced and the vertical lines non-uniformly spaced such that when developed the three dimensional structure formed by the sheet is stepped.

7. A substantially planar sheet of relatively inflexible material as claimed in claim 5 in which the grid upon which each pattern unit is based has the horizontal lines non-uniformly spaced such that when developed the three dimensional structure formed by the sheet is curved.

8. A structure consisting of and including a sheet as claimed in any one of the preceding claims.

9. A sheet of relatively inflexible material substantially as hereinbefore described with reference to, and as shown in, Figs. 1 and 2, or Figs 3 and 4, or Figs. 5, 6A, and 6B, or Figs 7 and 8, or Figs. 9 and 10, or Figs. 11 and 12, or Figs. 13 and 14, or Figs. 15, 16A, and 16B, or Figs. 17 and 18, or Figs. 19 and 20, or Fig. 21, or Fig. 22, of the accompanying drawings.

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